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Analysis of IUE Observations of Hydrogen in Comets

by Michael R. Combi

Space Physics Research Laboratory

Department of Atmospheric, Oceanic and Space Sciences

University of Michigan

Ann Arbor, MI 48109

Co-Investigator, Paul D. Feldman

Department of Physics and Astronomy

The Johns Hopkins University

Baltimore, MD 21218

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Abstract

The 15-years' worth of hydrogen Lyman-α observations of cometary comae obtained with the International Ultraviolet Explorer (IUE) satellite had gone generally unanalyzed because of two main modeling complications. First, the inner comae of many bright (gas productive) comets are often optically thick to solar Lyman-α radiation. Second, even in the case of a small comet (low gas production) the large IUE aperture is quite small as compared with the immense size of the hydrogen coma, so an accurate model which properly accounts for the spatial distribution of the coma is required to invert the inferred brightnesses to column densities and finally to H atom production rates. Our Monte Carlo particle trajectory model (MCPTM), which for the first time provides the realistic full phase space distribution of H atoms throughout the coma has been used as the basis for the analysis of IUE observations of the inner coma. The MCPTM includes the effects of the vectorial ejection of the H atoms upon dissociation of their parent species (H_2O and OH) and of their partial collisional thermalization. Both of these effects are crucial to characterize the velocity distribution of the H atoms. This combination of the MCPTM and spherical radiative transfer code had already been shown to be successful in understanding the moderately optically thick coma of comet P/Giacobini-Zinner and the coma of comet Halley that varied from being slightly to very optically thick. Both of these comets were observed during solar minimum conditions. Solar activity affects both the photochemistry of water and the solar Lyman-a radiation flux. The overall plan of this program here was to concentrate on comets observed by IUE at other time during the solar cycle, most importantly during the two solar maxima of 1980 and 1990. Described herein are the work performed and the results obtained.

I. Introduction

There have been many studies of the process of photodissociation and photoionization of water by solar ultraviolet radiation which provide information about the overall rate and the various branching ratios (Festou 1981; Wu and Chen 1993; Budzien, Feldman and Festou 1994). Such information is not only centrally important in the study of comets, but is also important for a wide range of planetary atmosphere studies (Huebner, Lyon, and Keady 1992). Oppenheimer and Downey (1980) noted the importance of the variation of solar Lyman-α to the dissociation of water, and concluded that the overall rate could vary by up to a factor of two with solar activity. In addition, the ratios between the ionization, H + OH, and $H_2 + O(^1D)$ branches should also vary with solar activity. Because of this the water lifetime used both in the interpretation of OH and H observations varies over the solar cycle. We have undertaken the task to test this variation by comparing the IUE observations of the major water photodissociation products (i.e., H and OH) and the resultant water production rates between solar minimum and solar maximum with models calculations which account for the variations in lifetime and branching ratios.

Recently Budzien et al. (1994) have systematically studied the effect of solar activity variations on the photochemistry of water as seen in the observations of OH by IUE in a number of comets. They have re-evaluated the effect of the variable solar UV on the lifetime of water and on the branching ratios of the major dissociation and ionization branches. Their detailed results are parametrized on the basis of measured solar activity indices (e.g., F10.7-cm and He 10,838Å) and can produce a continuous distribution of results. It is most interesting to note that those results assembled by Combi & Smyth (1988b) and Combi (1989; see Combi and Feldman 1993 for a discussion) for typical solar maximum and minimum cases are consistent with the comparable limiting cases found more recently by Budzien et al. Therefore, the analyses of several sets of solar minimum results published in a series of papers on various emissions of water photodissociation products in comets P/Giacobini-Zinner and P/Halley by our extended group are reasonably self-consistent with the approach of Budzien et al. These include H Ly-α from Pioneer Venus in Halley by Smyth, Combi, and Stewart (1991) and Smyth, Marconi, & Combi (1995),

HI-Ly-α from IUE in comets P/Giacobini-Zinner and Halley by Combi and Feldman (1992 & 1993), H Balmer–α from ground based Fabry-Perot measurments by Smyth et al (1994), OH from IUE in comet Halley by Combi, Bos, and Smyth (1993), and O(^{1}D) in Halley again from Fabry-Perot measurements by Smyth et al. (1995).

An important part of the problem in understanding the emission of Lyman-α from a comet is to know the Lyman-α flux from the sun and the shape of the line profile. The solar Lyman-α line is on the order of 1 Å wide, which is very broad as compared with the portion of the line seen by hydrogen atoms in coma of a comet at some point in its orbit (< 0.2 Å from a range of about ± 20 km s^{-1}). To complicate the situation, a typical comet is in a highly elliptical orbit that causes the radiation scattered by the cometary H atoms to be Doppler shifted by as much as another ± 0.2 Å from the center of the line. Therefore the emission brightness of cometary hydrogen is determined largely by the flux at or near the center of the line rather than by the integrated line flux which is typically measured by instruments on satellites like SME and UARS, or can be estimated from other solar activity indices such as the F10.7-cm or He-10830Å fluxes. The integrated line flux is known to vary on long time scales with the 11-year solar cycle and on short time scales with solar rotation. The solar line profile has shown a self-absorption in the center that has been measured (Lemaire et al. 1978) during solar minimum conditions but there has been considerable controversy over whether the shape of the line changes with the integrated flux.

Direct solar observations have indicated that the line-center flux may vary more than integrated flux based on a reconstruction of a full solar disk spectrum from a number of smaller scale observations (Lean 1987). That is, when the integrated flux is large, the central absorption fills in. However, years of spacecraft observations of the interstellar medium both by Pioneer Venus (Ajello et al. 1987) and Voyager (Shemansky and Judge 1982; Shemansky 1991) are consistent with little or no variation of the ratio of the line-center to integrated flux.

This question is of considerable importance for various problems in solar physics and earth and planetary science for which the accurate knowledge of the solar Lyman-α flux (and especially the level at line center) is critical. All planet atmospheres are essentially at a zero Doppler shift

with respect to the solar line since they are in circular orbits. The comets observed by IUE cover a wide range of Doppler shifts because of their highly elliptical orbits. To this point in time in our large scale coma modeling (Combi & Smyth 1988b; Smyth, Combi and Stewart 1991) and in the radiative transfer calculations (Combi & Feldman 1992 & 1993) we have used the average quite-sun full-disk H Lyman-α profiles determined by Lemaire et al. (1978), because the comets were all observed at or near solar minimum conditions. However, work by Fontenla, Reichmann and Tandberg-Hanssen (1988) who observed the Ly-α profile in various local regions of the sun during various levels of activity found that the shape of the profile changes dramatically. McGrath and Clarke (1992), in an analysis of 14 years of IUE observations of HI Ly-α from Saturn, compared the observed nominal brightness with that of Jupiter. Interestingly, they found that the Saturn and Jupiter observations scaled quite well with one another except during the 1980 solar maximum period when the Saturn brightness was nearly 40% higher than Jupiter. Because the Saturn brightness is determined by the solar Ly-α line center brightness, whereas the Jupiter brightness is more indicative of the entire line, the simplest explanation is that the line-center of the solar Ly-α line did not have a central reversal during the 1980 solar maximum period.

This report describes the analysis of the sets of IUE observations of H Ly-α in two bright comets observed during the two most recent solar maximum periods. The goals were: (1) to test the combination of the hybrid H coma and spherical radiative transfer models (first applied to the six days of observations of comet P/Giacobini-Zinner and on the 28 days of Halley data), in order to compare the inferred water production rates with published observations of OH, (2) to test observable effects of solar activity dependent photochemistry on the H coma, and finally (3) to see if the comet observations yield information about the variation of the solar Ly-α line profile shape over the solar cycle.

We present here the status as of the end of our project on the analysis of observations of hydrogen Ly-α emission from comets Bradfield (1979 Y1) and Austin (1989 X1) which were taken during the two most recent solar maximum periods, 1980 and 1989, with the International Ultraviolet Explorer (IUE) satellite. IUE observations of hydrogen Ly-α emission from comets

21P/Giacobini-Zinner and 1P/Halley, made during the 1985-1986 solar minimum, and their comparison with self-consistently analyzed OH were found to be consistent with the standard water photodissociation picture. These model analyses accounted for the important detailed physical mechanisms: vectorial ejection, the solar Ly- α line profile, partial collisional thermalization of H atoms, and a spherical radiative transfer calculation for solar Ly-α resonance scattering. The variation of the far solar UV with solar activity (including Ly-α) effects the photochemistry of water by changing both the overall photochemical rates and various branching ratios. In addition, the cometary hydrogen Ly-α brightness is regulated by the absolute flux and the shape of the solar Ly-α line profile because comets scatter only a portion of the solar line within a narrow range of wavelengths Doppler shifted from line center according to the heliocentric velocity of the comet.

II. IUE Observations

The IUE spacecraft, its spectrographs and the standard calibration and reduction have been discussed in detail by Weaver et al. (1981) and more recently by Budzien et al. (1994). See also a review article by Feldman (1991). The hydrogen Lyman-α emission was recorded in spectra obtained with the short wavelength primary (SWP) SEC vidicon camera of IUE that covers the spectral range of 1150-1950 Å. The measurements of the commonly observed (0-0) band of OH at ~3090Å in comets were obtained using the long wavelength primary (LWP) camera. For comet observations the larger entrance aperture (10 x 20 arc seconds) has most often been used.

For calculating the Ly-α fluxes we have adopted and automated the procedure which Harris (1993) developed for studying the Jovian aurora. It accounts for the long term degradation of the detector near the center of the large aperture at Ly-α caused by the years of burning-in by stellar observations. Harris constructed a series of yearly flat-fields which were convolved with the observed aperture image on the spectral plane, before integrating to calculate the total line flux. We automated his general system for use in reducing the comet observations. For this study we have analyzed the nucleus-centered observations of comets Bradfield (1979 Y1) and Austin (1989 X1).

IUE observations for these comets have been discussed in primary publications by Weaver et al. (1981)

III. Reduction of IUE Spectra to Lyman-α Brightness and Calculation of Water Production Rates

Work during this year has concentrated on model analysis of a set of Lyman-α observations made of comets during near solar maximum conditions. In contrast, the two previously published works (Combi & Feldman 1992 & 1993), describing work performed under a previous ADP grant, involved the analysis of extensive sets of observations made of two solar minimum comets, P/Giacobini-Zinner and P/Halley during 1985 and 1986. In addition to simply analyzing the H Lyman-α data comparing solar activity effects was one of the major objectives of this program. This analysis addresses other objectives, as mentioned in the Introduction. In order to perform a model analysis of the Lyman-α emission from a SWP IUE observation a rather lengthy many step process is involved:

• 1. Obtain the spectra from the data archive: including comet and coordinating sky spectra,

• 2. Determine Lyman-α flux from each spectrum,

• 3. Construct three sets of estimated time-dependent production curves for the comet (high, medium and low production rate estimates),

• 4. Run three sets of hybrid hydrodynamic/Monte Carlo models for the time-variable coma outflow conditions along the orbit (Combi 1989),

• 5. Run three time-dependent H coma Monte Carlo models for each observation date and extract the H atom density profiles (Combi and Smyth 1988a; Combi and Feldman 1992)

• 6. Run three spherical radiative transfer calculations (Anderson and Hord 1977)

• 7. Run three IUE aperture line-of-sight integration calculation

• 8. Obtain and determine an appropriate solar Lyman-α flux for the day in question at the solar-rotation-corrected heliographic longitude of the comet

• 9. Finally, from the observed comet Lyman-α brightness (less the geocorona "sky" contribution), interpolate the best water production rate from the three model estimates.

• 10. Perform steps 3 through 9 for both solar active and solar quiet conditions.

In order to compile the set of possible SWP IUE observations of comets, we used a combination of the summary IUE publication of Festou (1990) which covers comet observations through the late 1980s and on-line searches of the archive. The Co-Investigator, Paul Feldman, who was involved with the acquisition of many of these data, helped in obtaining much required information. After examining the entire data set we found that for quite a number of the faint comets no separate geocorona sky observations were made. The geocorona emission varies intrinsically with time (from changes in the geocorona itself and the solar Lyman-α flux), and with the position and pointing of the IUE spacecraft itself. The typical geocorona brightness is on the order of 1000 Rayleighs, but at any particular time and depending on the zenith angle of the observations the actual value may vary by more than factor of 2 up or down. Therefore, if a comet is intrinsically very bright (more than several tens of kiloRayleighs) an estimation of the geocorona background may be quite reasonable. Some of the bright comet observations are well in excess of 100 kiloRayleighs. However, for faint comets or for observing the coma offset from the nucleus, obtaining a reasonably accurate assessment of the geocorona brightness becomes more important.

For past work in determining the Lyman-α brightness from a SWP spectrum we used a program in the comet analysis package at Johns Hopkins. Since then Dr. Walt Harris, of the Univeristy of Wisconsin (formerly from the University of Michigan), has carefully studied a number of aspects of extracting Lyman-α fluxes from observations of extented objects in connection with his work (Harris 1993) on observations of Jupiter aurorae. This includes the variation of the detector sensitivity across the large aperture and its degradation with time. He provided us with flat fields that he determined from observations covering the entire lifetime of IUE, as well as his IDL routine for extracting Lyman-α brightnesses for Jupiter auroral observations. We adapted and automated his program especially for comet observations. Figure

1a shows a plot of the width integrated scan along the slit for the flat field (dashed line) and for an observation of comet Bradfield (solid line) obtained February 13, 1980. Below this in Figure 1b is shown the integration along the length of the large aperture of the flat-field corrected comet emission. From this type of process SWP observations of comet and geocorona emission were reduced to Lyman-α brightnesses in Rayleighs.

Steps 3, 4 and 5 (above) are coordinated for a single comet, given its time history, either from published IUE observations of OH or from other sources, usually groundbased OH or $O(^1D)$ observations. Three sets of estimates for the production rate variation are made at high, low and medium estimates for the gas production rate. The models were run for both the expected active solar conditions, consistent with the recent OH model analysis of Budzien et al. (1994), and for quiet solar conditions, in order to test the sensitivity of the extracted water production rates to photochemical assumptions. The results from step 5 are H atom density profiles which are then used as input to the radiative transfer calculation and line-of-sight IUE aperture integration (steps 6 and 8). The solar Lyman-α flux has been estimated from the on-line data base of F10.7 cm and/or He 10830 Å measurements (Cochran and Schleicher 1993).

Table 1 shows the compilation of the first part of the data analysis, the Lyman-α fluxes determined from the improved reduction procedure. For completeness we also include in this table our reduction of some spectra of comet Wilson in 1987 and comet P/Encke in 1980. There were no adequate geocorona measurements corresponding to either of these comet observations.

IV. The Effect of Solar Activity Variations on Water Production Rates Calculated from H Lyman-α Observations

A major goal of the work in this project was to examine the effect if any of solar activity on observational aspects of the production of cometary H and OH. It is clear from the results of Budzien et al. (1994) and even those of Cochran and Schleicher (1993) that the inclusion of solar activity dependent photochemical effects on the lifetime of water yields important differences on the extracted water production rates extract from OH observations. To examine this effect in the H

observations we performed two complete sets of model calculations for the three levels (high, medium and low) of water production rate and for every observation of comets Bradfield and Austin: one including solar active photochemistry and the other including solar quiet photochemistry. The details on the various reaction branching ratios, and by implication on the OH and H velocity distributions were given in the original paper by Combi and Smyth (1988b), and have been revised and made more general by Budzien et al. (1994). In Table 2 we summarize the results for the three sets of model runs for each comet.

What is clear from the results is that over a range of heliocentric distances the assumption of solar active or solar quiet conditions on the calculation of production rates from H Lyman-α measurements makes only a few percent difference. This is in stark contrast to the results of Budzien et al. (1994) for OH who find that solar variations of 30% or more, depending on the heliocentric distance and the real size (in km) of the IUE aperture. Similar sensitivity has been discussed for ground-based obervations of OH (Cochran and Schleicher 1993; Schleicher et al. 1998). The important implication of this is that the extraction of water production rates from H Lyman-α observations is actually less sensitive to the assumptions of solar activity dependent photochemistry than from OH observations. In hindsight, the reason for this is clear. Whereas in most weak to moderately active comets, when OH is produced even with its appropriate velocity (~1.05 km/s) from a dissociating water molecule, the velocity distribution is still a fairly narrow beam concentrated in the radially outward direction. H atoms on the other hand, even after one or two collisions have a highly random and high-speed velocity distribution because they are produced many with velocities of 8, to 18 to more than 20 km/s per second.

Therefore, whereas there is a severe reduction of the amount of OH relative to the parent H_2O in the inner coma ($r < 50{,}000$ km) because it is still being produced there and the velocity remains beamed radially, H atoms produced at even large distances are sprayed more isotropically even back into the inner coma. This might have been predicted from previous results of earlier modeling studies of the H coma (Combi and Feldman 1992, 1993), on the basis of the radial density

distribution, which is not far from $1/r^2$ even at fairly small distances to the nucleus. However, the point is fairly subtle and hindsight is always more clear.

V. Water Production Rates for Comets Bradfield and Austin

The other major aspect of this work is the calculation of water production rates from obsrvations of the H Lyman-α emission and the comparison of those determined from a reasonably self-consistent analysis of IUE observations of OH. This is the same exercise we had performed for the solar quiet comet P/Halley and P/Giacobini-Zinner (Combi and Feldman 1992 &1993). Table 3 shows the results of the extracted production rates from the H Lyman-α emission compared with those calculation by Budzien et al. (1994) using nearly contemporaneous IUE measurements of cometary OH using the LWP camera. In most cases we have obtained a more complete set of these data directly from Dr. Budzien (private communication) than actually appear in their published paper.

In addition to nucleus-centered obervations of comets Bradfield and Austin, a number of offset observations were made. The brightness is obviously lower for offset observations, compared with nucleus-centered, and generally yields a somewhat higher relative uncertainty because of the large contribution of the subtracted geocorona brightness. However, extraction of production rates from offset observations can be quite useful, because they could be sampling a region of the coma where optical depth effects are much lower, and therefore the inversion process with the model is more nearly linear, reducing somewhat the uncertainty. In Table 3, production rates extracted from offset observations are marked with the footnote (c).

As discussed in the Introduction, if any systematic difference in comparing water production rates from OH and H should appear, one might conclude that it would be for the 1980 solar maximum, but not the 1990 solar maximum. This again is based on the 14-years of IUE observations H Lyman-α at Jupiuter and Saturn (McGrath & Clarke 1992). Examination of the 1980 results for comet Bradfield indicates similar levels of differences between water production rates from H (ours) and OH (Budzien et al. 1994) as we had found for the solar minimum comets

Halley and Giacobini-Zinner. However, the differences are generally evenly split in either direction. If we were to see the effect cites by McGrath and Clarke we would expect to get systematically too large production from H observations because the solar Lyman-α flux in the center of the line might be larger because of the filled-in profile. This seems not to be the case. The agreement for comet Austin is quite good. Therefore, we would conclude based on our stude of solar active comets that for the purpose of determining water production rates from H Lyman-α observations that the use of the daily solar Lyman-α flux corrected for rotation in combination with the line profile shape of Lemairre et al. is quite adequate.

VI. Summary and Future Work in this Area

We have presented a study of the effects of solar activity on the observations and analysis of H Lyman-α observations obtained with IUE of comets Bradfield and Austin during the 1980 and 1990 solar maximum periods, respectively. We have compared alternative analyses of these comets with solar active and solar quite conditions, and have compared the solar active results with nearly contemporaneous IUE observations of OH. Our major conclusions are as follows. (1) The distribution of cometary hydrogen in the inner coma is not very sensitive to the details of the water photochemistry. This is in contrast with the extraction of water production rates from OH observations which are quite sensitive to the adopted values of the photochemical lifetimes. The cause of this lack of model sensitivity is undoubtedly due to the fact that most of the hydrogen is produced with large velocity (compared to the water outflow speed), thereby spraying H atoms uniformly and even back into the source region. The OH radical's "vectorial" velocity is comparable to the outflow speed and thermalization of that suprathermal component is more efficient than for H at larger distances from the nucleus. This is due in part to the small mass of the H compared with OH. (2) The comparison of water production rates from H and OH in comets Bradfield and Austin shows no systematic difference between the two solar maximum periods. Therefore, we do not see any evidence in the comet observations for a different structure for the

central region of the solar Lyman-α line as has been suggested by McGrath and Clarke (1992). (3) Finally, we believe that our results for H Lyman-α observations in four comets with IUE, and with other comets using other instruments, indicates that observations of H Lyman-α can serve as a useful indicator of water production in comets provided that the observations are analyzed with a model which includes all of the important physics and chemistry and that intercomparisons are made with other observations (OH, for example) which are analyzed with self-consistent models and model parameters.

Although the project is formally ended, we are continuing in an unsupported mode to formally present these results to the scientific community. These results will be presented at the 1998 Division for Planetary Sciences meeting to be held in Madison, Wisconsin, October 12-16, 1998. An abstract has been submitted (Reinhard, Combi and Feldman 1998) which will be published in the Bulletin of the A.A.S. A copy of the abstract is attached at the end of this report. Preparation of a formal publication is already underway and will be submitted to *Icarus* for publication by the end of the calendar year, to complete the set including our previous papers (Combi and Feldman 1992 & 1993) which were published there.

As a final comment, IUE has made great contributions to cometary science during its very useful and fruitful lifetime. It is a real shame that operation could not have been continued at least through the full recent aparition of comet Hale-Bopp (1995 O1), the comet of the century.

Table 1. IUE Lyman-α Brightness Reduced with the Harris Algorithm

Date	Spectrum/File	Brightness (kiloRayleighs)
	Comet Bradfield	
01/11/80	swp07628slg	165.300
	swp07630slg	154.400
01/16/80	swp07670slg	133.100
01/24/80	swp07758slg	29.000
	swp07759slg	31.100
	swp07760slg	31.900
	swp07761slg	31.200
	swp07763slg	51.100
01/25/80	swp07764slg	2.830
	swp07765slg	4.054
01/31/80	swp07820slg	36.100
	swp07821slg	5.433
	swp07822slg	6.018
	swp07823slg	6.526
	swp07824slg	3.900
02/07/80	swp07885slg	15.740
	swp07886slg	1.114
	swp07887slg	5.974
02/13/80	swp07939slg	8.117
02/21/80	swp07997slg	3.593
03/03/80	swp08157slg	1.904

Comet Austin

12/29/89	swp37919slg	0.543
05/11/90	swp38773slg	63.414
05/13/90	swp38781slg	59.872
05/16/90	swp38800slg	12.938
	swp38801slg	10.437

Comet P/Encke

11/03/80	swp10529slg	1.621
11/05/80	swp10546slg	6.434

Comet Wilson

11/08/86	swp29407	0.848
3/28/87	swp60640	13.095
3/29/87	swp30641	8.484
4/03/87	swp30698	20.047
4/10/87	swp30754	21.338
4/11/87	swp30755	3.479
4/22/87	swp30842	21.560
5/05/87	swp30918	21.285
5/12/87	swp30961	6.045
5/26/87	swp31049	13.169
6/08/87	swp31124	10.403

Table 2. Effect of Solar Dependent Photochemistry on H Lyman-α

Comet Bradfield

Solar Active Conditions

date	low Q	medium Q	high Q
1/11/80	168.7	178.0	184.7
1/16/80	116.2	125.0	134.2
1/24/80	80.19	90.14	96.23
1/31/80	46.67	58.29	66.82
2/07/80	23.20	29.91	35.76
2/13/80	12.55	16.86	20.92

Solar Quiet Conditions

date	low Q	medium Q	high Q
1/11/80	165.5	176.5	183.7
1/16/80	113.8	123.0	132.5
1/24/80	78.17	88.45	94.04
1/31/80	43.09	55.69	63.92
2/07/80	21.33	28.24	33.27
2/13/80	11.575	15.52	19.28

Table 2. (continued)

Comet Austin

Solar Active Conditions

date	low Q	medium Q	high Q
5/11/90	57.79	71.44	79.85
5/13/90	48.46	59.84	67.68
5/16/90	38.80	51.52	58.88

Solar Quiet Conditions

date	low Q	medium Q	high Q
5/11/90	52.88	66.72	75.57
5/13/90	44.17	56.86	65.50
5/16/90	35.80	48.06	55.15

Table 3. Comparison of Water Production Rates from IUE H and OH

r (AU)	D (AU)	Q (OH)[a]	Q(H)[b]
		Comet Bradfield	
0.72	0.60	1.53×10^{29}	1.35×10^{29}
0.80	0.41	7.8×10^{28}	6.0×10^{28}
0.93	0.20	4.3×10^{28}	2.4×10^{28}
			[c] 3.9×10^{28}
			[c] 4.1×10^{28}
			[c] 3.9×10^{28}
1.03	0.29	2.9×10^{28}	
		2.8×10^{28}	3.8×10^{28}
			[c] 4.6×10^{28}
			[c] 5.4×10^{28}
			[c] 6.2×10^{28}
1.15	0.53	1.72×10^{28}	2.1×10^{28}
1.25	0.76	1.18×10^{28}	0.96×10^{28}
1.56	1.48	0.22×10^{28}	
		Comet Austin	
.84	.42	11.2×10^{28}	
.88	.38		7.6×10^{28}
.92	.35	9.1×10^{28}	9.9×10^{28}
.98	.30	7.0×10^{28}	5.0×10^{28}

Notes to Table 3

a. Water Production rates from OH observations by Budzien et al. (1994)

b. Water production rates from H Ly-α observations, this study.

c. Data marked with footnote c were obtained from measurements offset from the nucleus.

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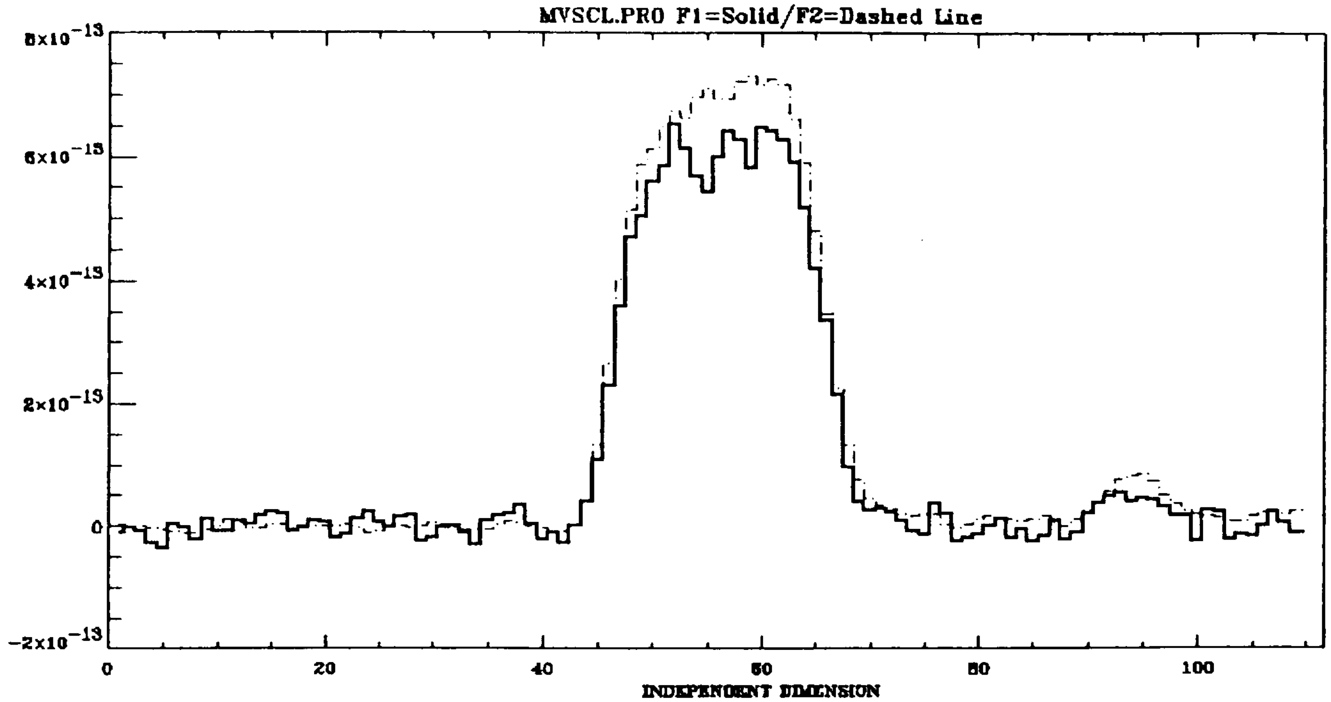

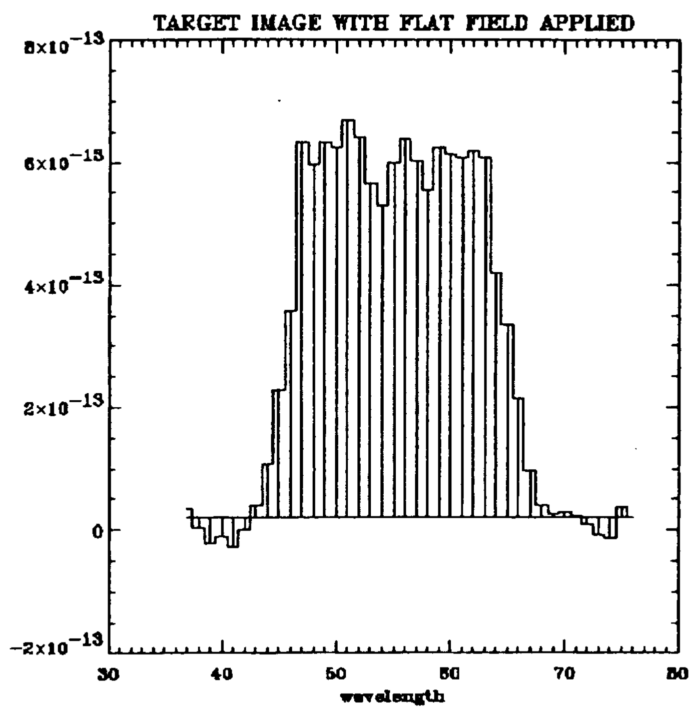

Figure 1. Calculation of Integrated H Lyman-a fluxes from the IUE large aperture observations. The solid line in the top plot is the spatial profile along the long axis of the IUE large aperture of a comet observation (Comet Bradfield on February 13, 1980). The dashed line is the spatial profile of the flat field. In the bottom plot is the integrated comet profile corrected for the flat field deviations. The flat field deviations have become worse of the years because of continual observation of bright point source objects near the center of the large aperture.

An Analysis of IUE Observations of the Hydrogen Lyman-α Comae of Comets during Solar Maximum

A.A. Reinard (U. Michigan), M.R. Combi (U. Michigan), P.D. Feldman (Johns Hopkins U.)

Observations of hydrogen Lyman-α were made of comets Bradfield (C/1979 Y1) and Austin (1989 X1) with the short wavelength primary (SWP) vidicon camera of the International Ultraviolet Explorer (IUE) satellite during times of maximum solar activity. See, for example, Weaver et al. (1981, Icarus 47, 449) and Budzien et al. (1994, Icarus 107, 164) for a discussion of the data acquisition and reduction procedures. These measurements were made both with the image of the nucleus centered on the IUE large aperture as well as displaced at various offsets. We have analyzed these data using a combination of the H coma Monte Carlo model and the spherical radiative transfer calculation which had been used already to analyze observations of solar minimum comets 1P/Halley and 21P/Giacobini-Zinner. The photochemical lifetime of water and the ratios for various dissociation and ionization branches are known to depend on the solar far UV spectral flux which varies with solar activity. The H coma model accounts for the time-variation of the gas production, the 3D orbital dynamics with heliocentric velocity dependent radiation pressure acceleration, full water and OH photochemistry, and explicit partial thermalization of H atoms by the collisionally thick water coma. The spherical radiative transfer model accounts for the axially symmetric distribution of the scattering of the solar Lyman-α radiation in the optically thick coma. We find that the analysis of H measurements is much less sensitive to the assumption of solar activity variations in the photochemistry than the OH measurements, and thus Lyman-α measurements might be used to provide a less model dependent method for extracting water production rates in comets compared with OH. A comparison between water production rates from the IUE Lyman-α measurements and those from other measurements is made.

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Paper presented by Alysha Reinard
Space Physics Research Laboratory
University of Michigan
2455 Hayward Street
Ann Arbor, MI 48109
Phone: 734-764-7221
Fax: 734-647-3083
Email: alysha@umich.edu
Point to URL:
Send email inquiries to: alysha@umich.edu

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